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COMPARISON OF COMPUTER-ACQUIRED PERFORMANCE DATA FROM SEVERAL FIXED SPACED PLANAR DIODES

by E. J. Manista, A. L. Smith, and R. B. Lancashire
Lewis Research Center
Cleveland, Ohio

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COMPARISON OF COMPUTER-ACQUIRED PERFORMANCE DATA FROM SEVERAL FIXED SPACED PLANAR DIODES

E. J. Manista, A. L. Smith, and R. B. Lancashire

NASA Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

Performance data are compared for thermionic diodes with various tungsten or rhenium emitters and niobium or molybdenum collectors. The planar converters have guard-ringed collectors and a fixed space of 10 mils (0.254 mm). The data were acquired using a computer. The parameters are the temperatures of the emitter T_E, collector T_C, and cesium reservoir T_R. The composite plots have constant T_E and varying T_C or T_R or both. The envelope and composite plots having constant T_E are presented.

The diodes were tested at increments between 1500 and 2000 K for the emitters, 750 and 1100 K for the collectors, and 520 and 650 K for the reservoirs. An average of 450 individual current, voltage curves were obtained for each diode.

INTRODUCTION

More power at lower temperatures is the goal for nuclear thermionic diodes. Providing that improvement means intensive testing of the best existing emitters and collectors, promising new electrode materials, and additives. To insure success, performance mapping must cover off-design as well as optimum operating conditions -- with special attention given to stability problems.

Moreover, predictions of the output characteristics of nuclear thermionic power system designs require that the properties of individual converter modules be taken into account. Indeed, all converters in the network cannot be assumed to be operating at nearly identical conditions if a reliable estimate of the system performance is desired.

Eventually, analytically based correlations may reduce the need for the detailed performance mapping of thermionic converters. Although that day may be near, the Lewis Research Center has accepted the need for massive thermionic converter data accumulation and has computerized its performance mapping test procedure as reported by Breitwieser, Manista, and Smith in reference 1.

A comparison of the performance data envelopes of four different combinations of electrode materials are reported herein. Specifically, the planar electrode combinations included in the comparison are emitters of physically and chemically vapor-deposited-tungsten against guard-ringed niobium collectors and etched-rhenium emitters against guard-ringed niobium and molybdenum collectors. More detailed data presentations of the performance maps of these electrode combinations are available in references 2-5. The converter structure is described by Speidel and Williams in reference 6.

All converters were tested with emitters at T_E's from 1500 to 2000 K in 50 K steps, collectors at T_C's from 750 to 1100 K in 50 K steps, and cesium reservoirs at various T_R's between 520 and 650 K. Composite plots of the output current density and voltage having constant T_E, and varying T_C and T_R, are presented.

TEST VEHICLE

A cross section of the planar, guard-ringed converter is shown in figure 1. The interelectrode spacing of 10 mils (0.254 mm) was determined from indicating surfaces on the emitter and collector body. Emitter, collector combinations investigated were etched-rhenium, niobium; etched-rhenium, molybdenum; chemically vapor-deposited-tungsten, niobium; and physically vapor-deposited-tungsten, niobium. Specific details of the emitter and collector electrodes and their preparation are given later. The converters were fabricated and filled with cesium by Thermo Electron Engineering Corporation.

Emitter Preparation

The rhenium emitters (Re) were fabricated from wrought, powder metallurgy material. After grinding the surfaces flat (#600 grit), the emitters were vacuum annealed at 2270 K for about one hour. They were then electro-etched before final converter assembly.

The physically vapor-deposited-tungsten emitter (PVD-W) was prepared on an arc-cast tungsten substrate. The emitter disc was ground flat and sandblasted before the coating process. About 1 to 3 mils of tungsten was then evaporated onto the substrate. During the coating process the mean substrate temperature was held at about 2600 to 2800 K while the evaporator was held at 3400 K.

The chemically vapor-deposited-tungsten emitter (CVD-W) was prepared from the chloride on an arc-cast tungsten substrate. The emitter was ground flat (#600 grit) and vacuum annealed at 2270 K for about one hour. It was electropolished at 10 to 12 volts in a 3 to 5 percent solution of NaOH to complete its surface preparation.

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Collector Preparation

The surfaces of the niobium (Nb) collectors and guard-rings were machined to a final finish of about 63 microinches. The pieces were then cleaned in a solution of trichloroethylene prior to converter assembly.

A molybdenum (Mo) collector and guard-ring were fabricated by evaporating about 0.2 mils of molybdenum onto the niobium pieces. During the vacuum deposition process the substrates were held at 870 K while the molybdenum filament was run at 2470 K.

TEST FACILITY

Test Stations

Each converter was mounted in one of six vacuum test stations which are coupled to a central instrumentation control panel. Each station has its own set of emitter, collector, and cesium-reservoir heat supplies. Thermal balance of the collector and reservoir is achieved through conduction to water lines.

Instrumentation

The current developed in the converter was measured by the voltage drop across either a 0.01- or 0.1-ohm, low-inductance, precision shunt. The emitter, collector potential difference was measured at the external shroud of the converter. No corrections were made for the voltage drop in the emitter support shroud since it is approximately 1.8 millivolts per ampere per square centimeter of electrode surface. The 1.55-square-centimeter collector face determined the current density. The guard-ring was electrically connected to the circuit on the opposite side of the shunt from the collector.

Collector and cesium reservoir temperatures were sensed by sheathed Chromel, Alumel thermocouples embedded in their respective converter structures. The couples were continuous and were brought through the vacuum wall of the test station into a common ambient cold junction zone. The temperature of the ambient zone was sensed by a Chromel, Alumel couple that was referenced electronically to 273 K. Two couples were inserted at each location. The cesium reservoir couples were in the copper block surrounding the copper tube containing the cesium (see Figure 1). Collector couples were within 3.05 millimeters (125 mils) of the collector surface. The Chromel, Alumel standard calibration for all four couples was verified by an in situ comparison against a Chromel, Alumel reference couple.

The emitter temperature was sensed by a sheathed high-temperature couple of tungsten, 5-percent-rhenium versus tungsten, 26-percent-rhenium. The couple was inserted to a depth of 6.35 millimeters (250 mils) from the emitter substrate edge and 3.3 millimeters (130 mils) from the active face of the emitter (see Figure 1). Compensating lead wires were attached to the couple on the interior of the test chamber and were brought out to a room temperature junction. The high-temperature couple was calibrated in situ against a black-body cavity (length-to-diameter ratio of five) in the edge of the emitter. The black-body cavity was observed through a window in the test station with a disappearing filament optical pyrometer. The optical path and pyrometer were calibrated against a National Bureau of Standards (NBS) tungsten strip lamp. The maximum uncertainty associated with the observed temperature is approximately ±10 Kelvin degrees. This estimate includes the accuracy of the NBS calibration, the reversal capabilities of the optical pyrometer and observer, and the effect of the approximate black-body cavity in the emitter. The temperature difference between the black-body cavity and the active face of the emitter is considered negligible for tungsten and is a maximum of 20 K for rhenium. These estimates are based on a one-dimensional heat balance of the radiation across the interelectrode gap and the heat conducted through the emitter. This model neglects any heat flow through the emitter-support shroud since the electron bombardment filament was designed to nullify this heat path. Electron cooling and heating effects on the surface temperatures are also negligible since the time interval over which the load is applied is very short and the converter is held at a low-current, retarded-voltage condition between tests.[1] The contribution of gaseous conduction is negligible.

TEST PROCEDURE

The computer-controlled data acquisition system is programmed to trigger the variable load at up to six different emitter temperatures during a given test interval of about 20 seconds. (The computer program was developed by E. Manista and C. Kadow of NASA-Lewis.) The system performs this task by monitoring the emitter temperature (the high-temperature couple output). When T_E reaches a predetermined value, the load is triggered. Temperature levels at which the load is to be triggered are introduced into the program by the operator as independent input data. The data recording program, synchronized with the application of the variable load, samples the J,V characteristics of the converter at 90 points during the load variation of approximately 10 milliseconds duration. Sample and hold amplifiers coordinate in time the collector current and collector, emitter potential difference. The data recording program then waits until the full load variation is over (by monitoring the load driving source) before recording the temperature data associated with the particular sweep. Between sweeps, these analog temperatures are converted by the computer to their values in degrees Kelvin and are printed out to aid the operator in setting appropriate test conditions.

The converters were mapped by fixing the temperatures of the cesium reservoir and the collector and by heating or cooling the emitter to the predetermined values. Through programmed trigger levels, emitter temperatures between 1500 and 2000 K were observed in 50 K increments. The temperature of the collector or of the cesium reservoir was then changed and the preceding procedure repeated. Table I give the nominal temperature conditions at which J,V data were obtained for each of the converters tested.

DATA PRESENTATION

Since the local computer can store and recall only a limited number of successive sweeps, the data are transmitted to the Lewis Central Computing Center for storage on magnetic tape and for some engineering calculations. The data from each converter are sorted into groups of common emitter temperatures and are displayed in order of ascending T_E on microfilm output. Both J,V and P,V (power density) curves are displayed on this output, with the J and P scales being determined by the maximum of each sweep. Two additional sorts are done by the Central Computer: The data are grouped by common emitter and collector temperatures and by common emitter and reservoir temperatures. The computer plots all the sorted J,V data on composite plots and displays them on the microfilm output. The current density scales on these plots are all common and limited to a maxiumum J of 30 amperes per square centimeter.

Figure 2 illustrates the density of data points used to define the observed optimum J,V envelope from a converter at a given emitter temperature. The presentation uses all the data accumulated at that emitter temperature for the converter and thus folds in the effect of both collector and cesium reservoir temperature variations.

RESULTS OF THE PERFORMANCE MAPS

Constant emitter temperature envelopes are given in Figures 3 to 6 for each of the converters to illustrate the performance obtained as a function of emitter temperature. Comparisons of the performance as a function of electrode combination are given in Figures 7 to 10 for emitter temperatures of 1700, 1800, 1900, and 2000 K.

Over most of the J,V operating points the etched-rhenium, niobium diode was superior. The exception being the region of low current density, near and below 6 amperes per square centimeter. At these conditions, all the diodes give nearly identical output. For current densities greater than 6 amperes per square centimeter the diodes can be ordered in terms of decreasing performance as etched-rhenium, niobium; chemically vapor-deposited-tungsten, niobium; and a toss-up between the physically vapor-deposited-tungsten, niobium and the etched-rhenium, molybdenum.

An anomaly and poor performance is shown by the etched-rhenium, molybdenum diode. One would expect its performance to have been equal to or a little better than that obtained from the etched-rhenium, niobium diode. The rhenium, molybdenum and the rhenium, niobium current, voltage curves are being examined in an attempt to uncover the primary reasons for this discrepancy.

CONCLUDING REMARKS

Detailed thermionic converter performance data from four different electrode combinations were compared at constant emitter temperatures of 1700, 1800, 1900, and 2000 K. The etched-rhenium, niobium electrode combination was found to give superior performance. Considerable lower performance was found for the etched-rhenium, molybdenum converter. Detailed examinations of the individual J,V curves are being made in order to ascertain the nature of this anomaly.

Table I

Nominal temperature conditions at which data were acquired for the fixed spacing converters. All converters were tested at emitter temperatures of: 1500, 1550, 1600, 1650, 1700, 1750, 1800, 1850, 1900, 1950, 2000 K. An exception was the etched-rhenium, niobium converter which was not tested at 1500 K.

CONVERTER	ETCHED-RHENIUM, NIOBIUM	PVD-TUNGSTEN, NIOBIUM	CVD-TUNGSTEN, NIOBIUM	ETCHED-RHENIUM, MOLYBDENUM
Cesium Reservoir Temperature, T_R K	525, 555, 575, 600, 625, 650	550, 575, 600, 625, 650	550, 575, 600, 625, 650	540, 560, 580, 590, 600, 610, 620, 640
Collector Temperature, T_C, K	875, 950, 1050, 1170	775, 850, 950, 1050	750, 850, 900, 950, 1000, 1050, 1100	750, 800, 850, 900, 950, 1000, 1050, 1100

References

1. R. Breitwieser, E. J. Manista, and A. L. Smith, "Computerized Performance Mapping of a Thermionic Converter With Oriented Tungsten Electrodes," Proc. IEEE Thermionic Conversion Specialists Conf., Carmel, Calif., Oct. 1969, pp 90-99, and NASA TM X-52714, 1969.

2. R. B. Lancashire, "Computer-Acquired Performance of an Etched-Rhenium, Niobium Planar Diode," Proc. IEEE Thermionic Conversion Specialists Conf., Miami, Fla., Oct. 1970, pp 487-491, and NASA TM X-2262, 1971.

3. R. B. Lancashire, "Computer-Acquired Performance Data from a Physically Vapor-Deposited-Tungsten, Niobium Planar Diode," NASA TM X-2330, 1971

4. A. L. Smith, "Computer-Acquired Performance Data from a Chemically Vapor-Deposited-Tungsten, Niobium Planar Diode," NASA TM X-2373, 1971.

5. E. J. Manista, "Computer-Acquired Performance Data from an Etched-Rhenium, Molybdenum Planar Diode," (to be published as NASA TM X), 1971.

6. T. O. Speidel and R. M. Williams, "Fixed-Space Planar Thermionic Diode With Collector Guard Ring," Proc. IEEE Thermionic Conversion Specialists Conf., 1968, pp 113-117.

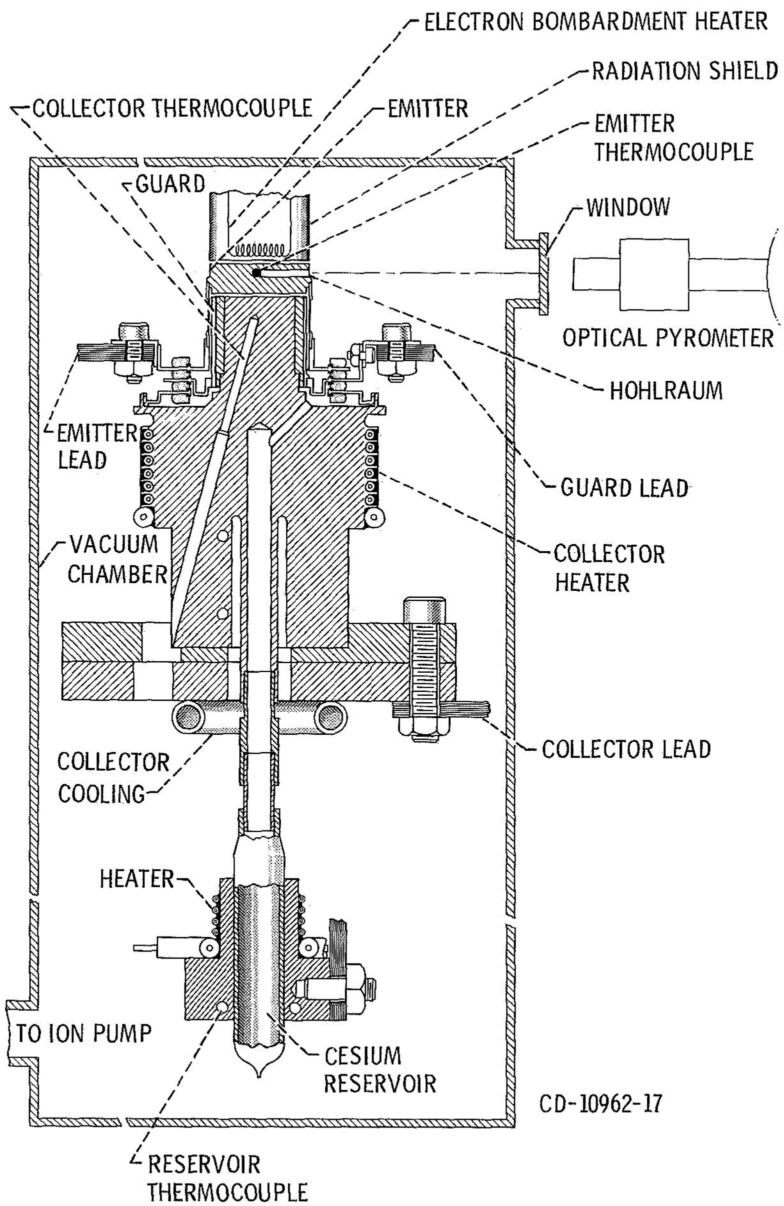

Figure 1. - Converter configuration.

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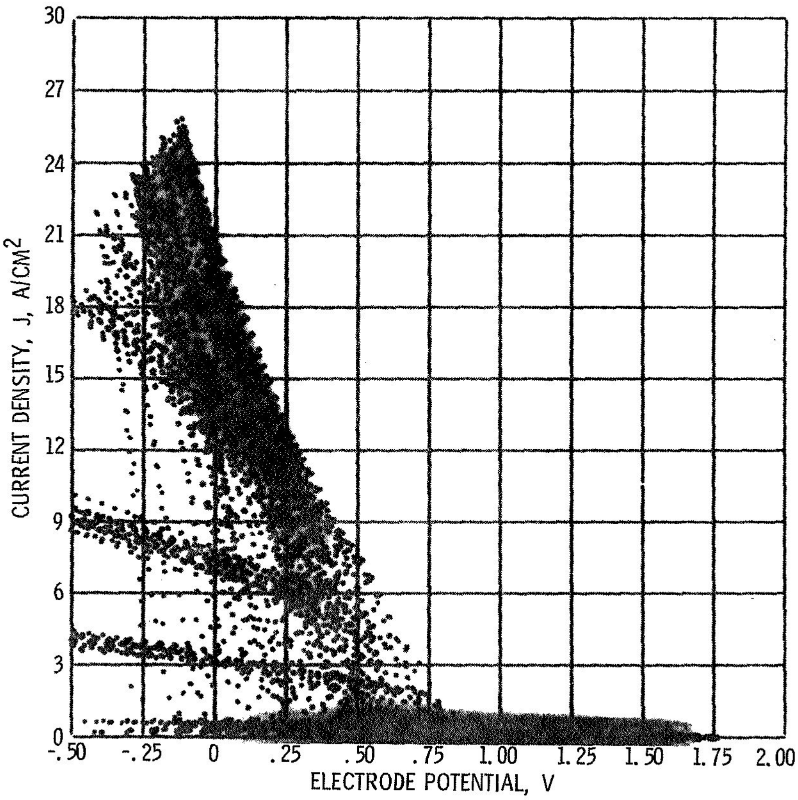

Figure 2. - Computer processed plot of current density, voltage data at constant emitter temperature of 1750 K for the etched-rhenium molybdenum converter. Collector temperature, 750 to 1100 K; cesium reservoir temperature, 540 to 640 K; interelectrode space, 0.254 millimeters (10 mils).

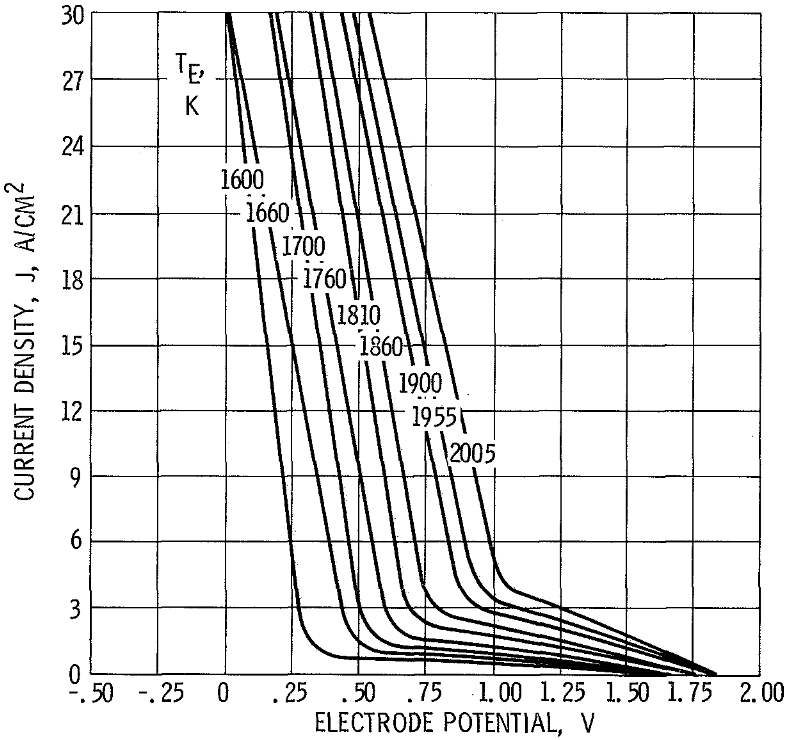

Figure 3. - Envelope curves for etched-rhenium, niobium planar converter at various emitter temperatures (from ref. 2).

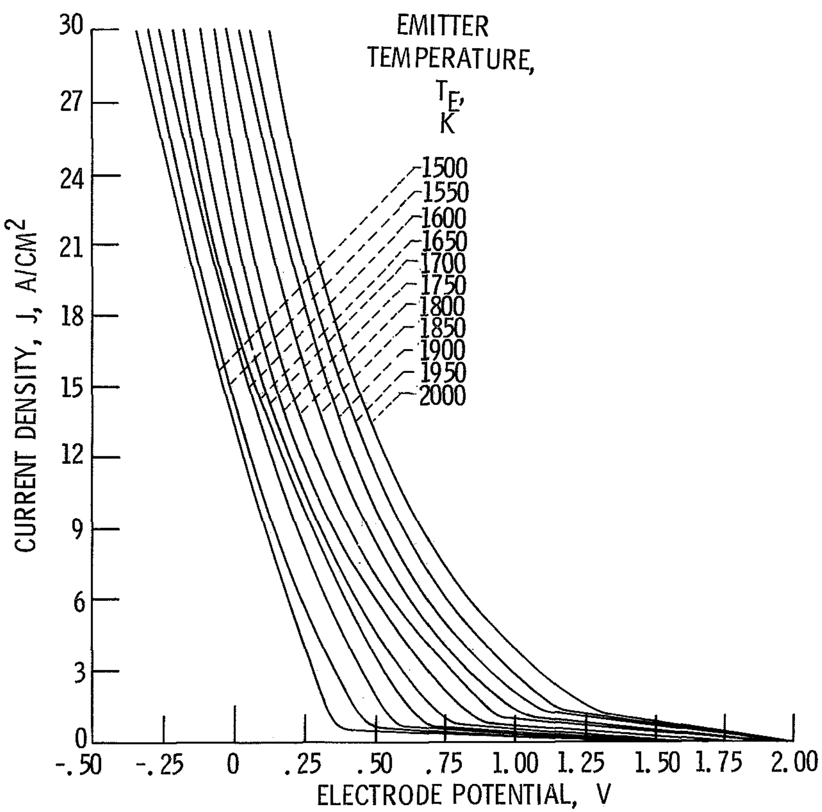

Figure 4. - Envelope curves for physically vapor-deposited-tungsten, niobium planar converter at various emitter temperatures. (From ref. 3).

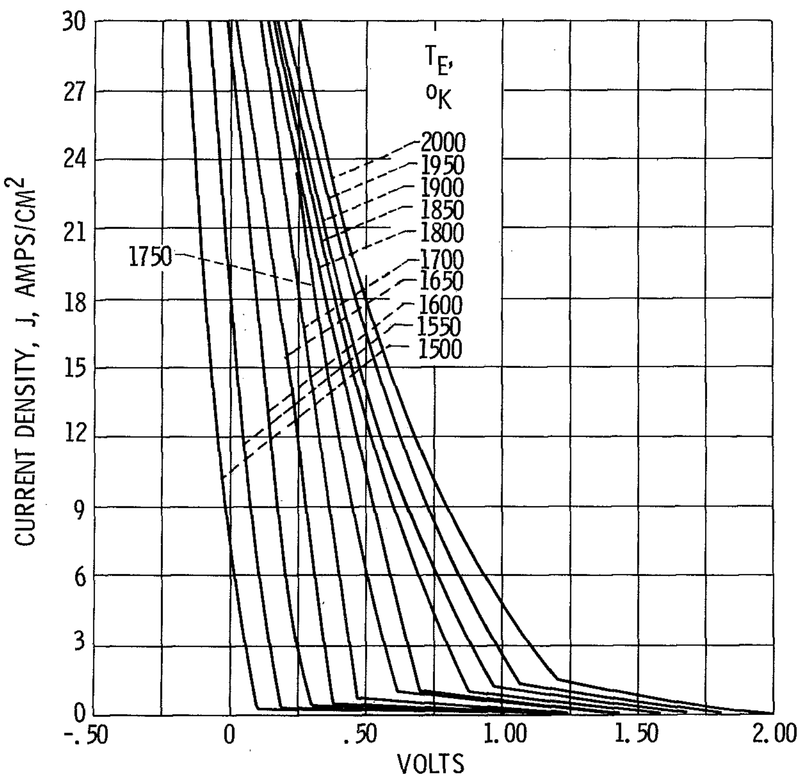

Figure 5. - Envelope curves for CVD tungsten, niobium planar converter at various emitter temperatures. (From ref. 4).

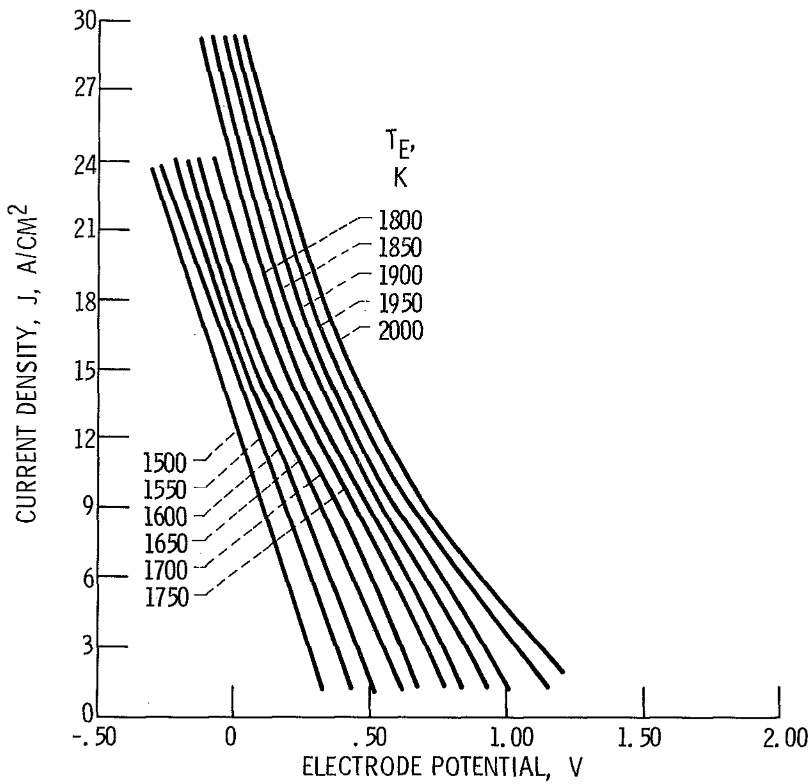

Figure 6. - Envelopes for etched-rhenium, molybdenum planar converter at various emitter temperatures. (From ref. 5).

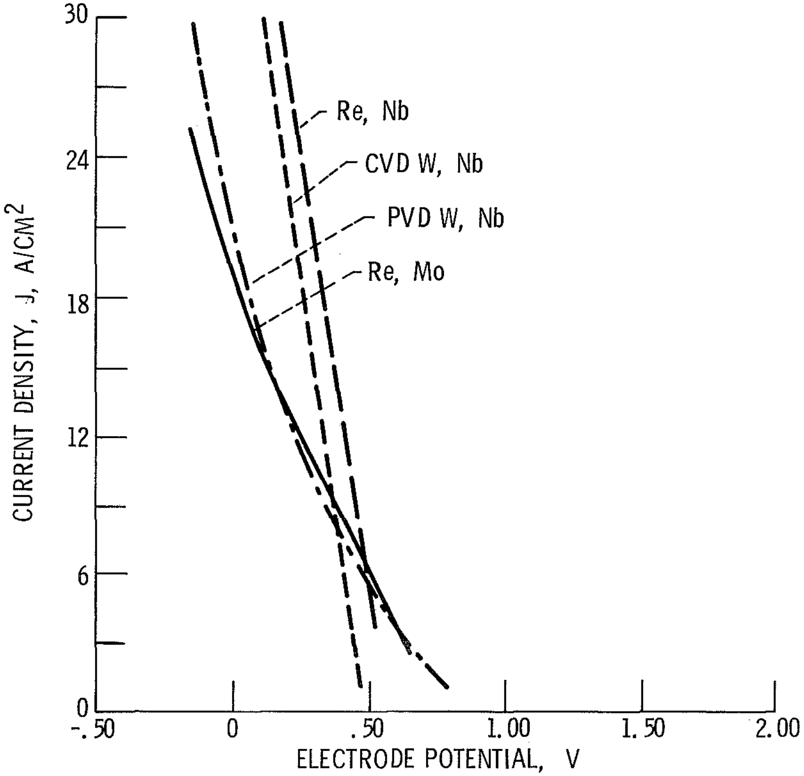

Figure 7. - Comparison of constant emitter temperature envelopes from various planar diodes. Emitter temperature, 1700 K; interelectrode spacing, 10 mils.

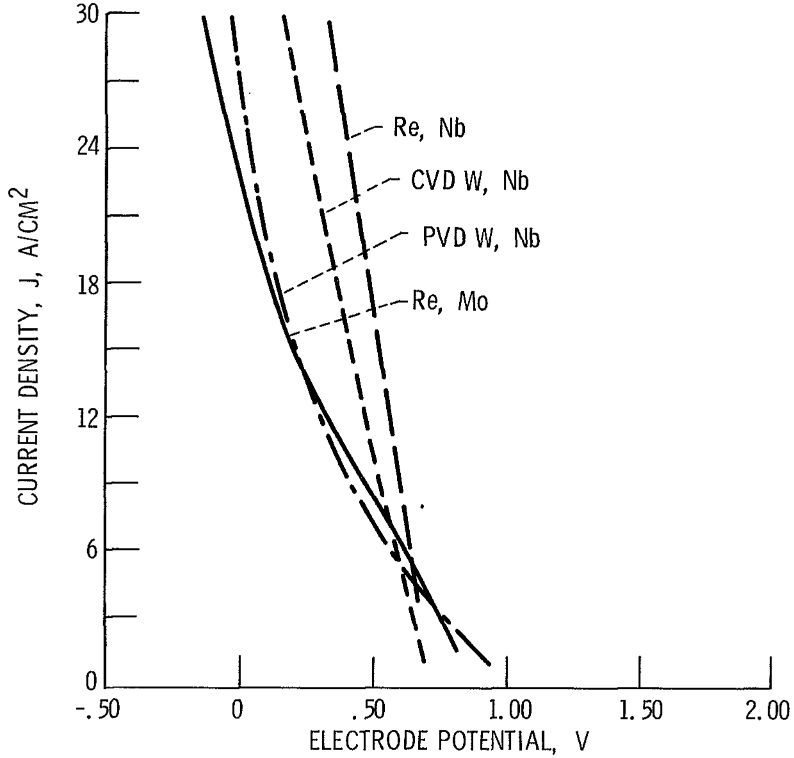

Figure 8. - Comparison of constant emitter temperature envelopes from various planar diodes. Emitter temperature, 1800 K; interelectrode spacing, 10 mils.

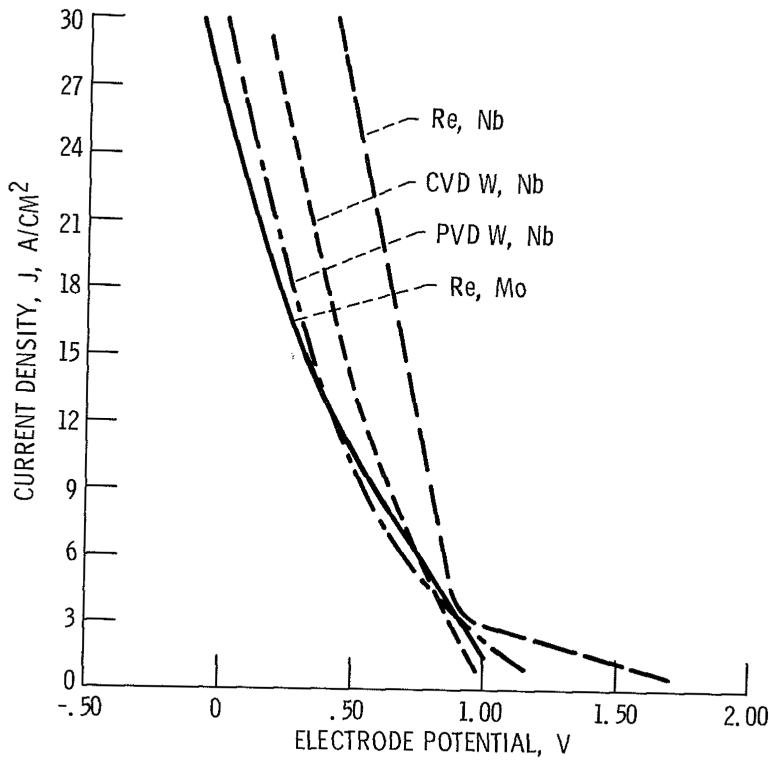

Figure 9. - Comparison of constant emitter temperature envelopes from various planar diodes. Emitter temperature, 1900 K; interelectrode spacing, 10 mils.

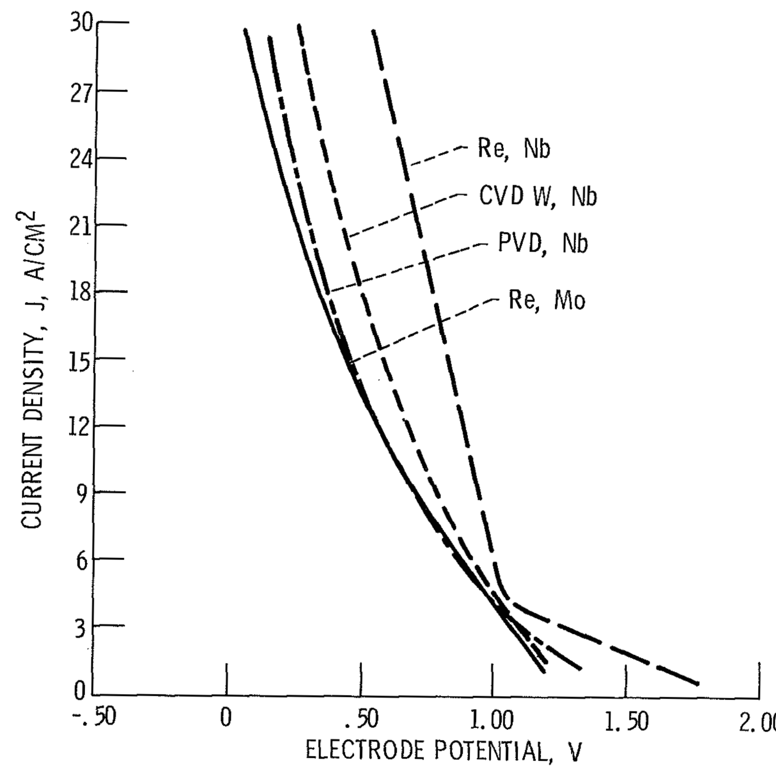

Figure 10. - Comparison of constant emitter temperature envelopes from various planar diodes. Emitter temperature, 2000 K; interelectrode spacing, 10 mils.